Development of soft flat-tube-based actuator for easy dressing and undressing

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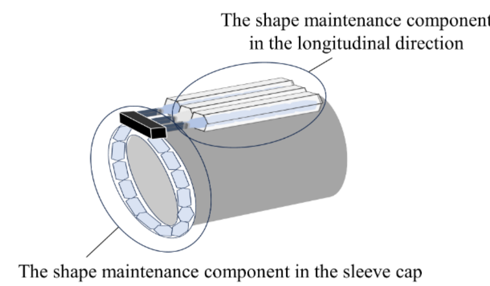
***Abstract*— Maintaining the shape of clothing without twisting or wrinkling, and ensuring a clear path for the arms, can facilitate the process of dressing and assisting with dressing. In this context, this study aims to develop a new device that increases the stiffness of clothing to maintain its shape. Flat tube based new soft actuator is developed for the stiffness incase in fabric. Normally, the flat tube actuator straightens and increases the stiffness. In this study, by making cuts, the flat tube actuator can be bent, resulting in attachment to rounded area of clothing. In addition, a friction reduction mechanism is installed along with the stiffness increased part by air flow mechanism to further facilitate dressing and undressing. The validity of the developed mechanism was verified by several experiments including human evaluation.**

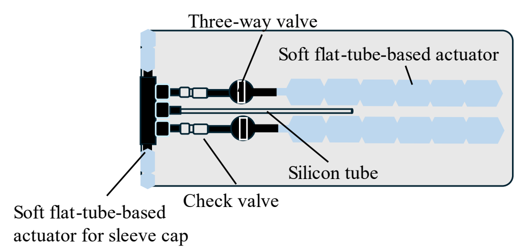
I. Introduction

This study presents a novel soft actuator that is incorporated into garments to maintain the garment's shape by adjusting stiffness while reducing the friction between the skin and garment. The daily routine of dressing and undressing is fundamental. However, for individuals with motor disabilities, this task can be significant challenges. Caregivers assisting such individuals must exercise caution to avoid damaging the clothing, injuring the skin, or affecting any body part. During dressing or undressing, garments often become “twisted,” complicating the process of rectifying these entanglements. Preventing such twisting is, therefore, critical to streamline the changing process [1]. By maintaining the garment's shape without inducing twists or wrinkles and ensuring a clear passage for the arms, the dressing and assistance procedures can be greatly simplified. This study focuses on upper body garments and presents a novel device that increases clothing stiffness, as depicted in Fig. 1, to maintain its shape. Additionally, the device features mechanisms to reduce friction during clothing changes, further facilitating the process.

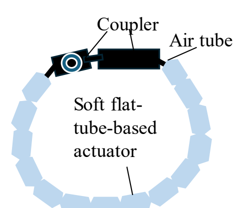
Wearable devices capable of varying their stiffness and incorporating fabric have been developed [2][3]. However, there has been limited focus on applications in dressing and undressing. An example is the pneumatic smart adaptive belt developed by Helps et al. [4], which can loosen the belt through air pressurization. Unfortunately, they did not consider the need for expansion and stiffness increase in the arm and leg areas of garments to prevent twisting and wrinkling, aspects crucial for dressing and undressing. Additionally, the function of friction reduction has also not been considered.



(a)Whole design



(b) Detailed structure of the shape maintenance component in the sleeve cap



(c) Detailed structure of the shape maintenance component in the longitudinal direction

Figure 1. Whole design of the developed soft flat-tube-based actuator, and detailed structures of the shape maintenance components in the longitudinal direction and sleeve cap

II. Soft Actuator for Easy Dressing and Undressing

As a first step, we focused on the sleeve area and developed a sleeve equipped with soft actuators along the sleeve cap and in the longitudinal direction of the sleeve. Fig. 1(a) shows the overall view of the structure. The structure of the soft actuators positioned along the sleeve cap (Fig. 1(b)) and the longitudinal direction (Fig. 1(c)) of the sleeve is also shown. The main components in both components are soft actuators.

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The soft actuators, designed with cuts in flat tubes, can be bent flexibly. In the sleeve cap area shown in Fig. 1(c), in addition to the cuts, the thickness of the top and bottom surfaces is varied, allowing bending to occur by inflating them. When air is introduced, the soft actuator expands the garment, maintaining its shape. The expansion of the sleeve cap also increases the width of the sleeve opening. Along the longitudinal direction of the sleeve, silicone tubes are added to the soft actuators, with air flowing out from their outlets to reduce friction between the skin and the garment (see Fig. 1(b)). A notable feature is that all the soft actuators are controlled by air flowing through a single channel.

III. Evaluation of Feasibility

A. *Maintaining of the shape of sleeve cap*

Fig.2 shows the experimental setup. The sleeve with stiffness and friction variable soft actuator was fixed on the stand. The load cell (IMADA，ZTS-DPU-50N) attached on the automatic poisoning stage (Orientalmotor，DRLM42G-04A2PM-K) was moved downward along the z-axis at 1.0mm/s, and the sleeve cap of the garment is pushed downward. The load was measured by force gauge (IMADA, ZTS-i). Measurements were taken three times, both with and without air pressurization.

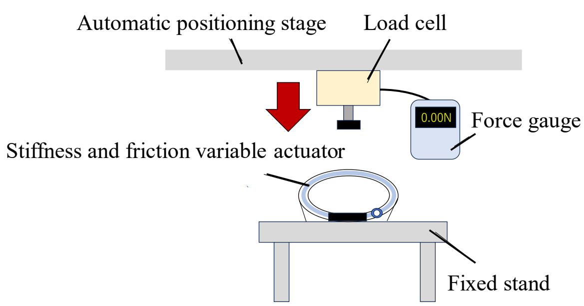
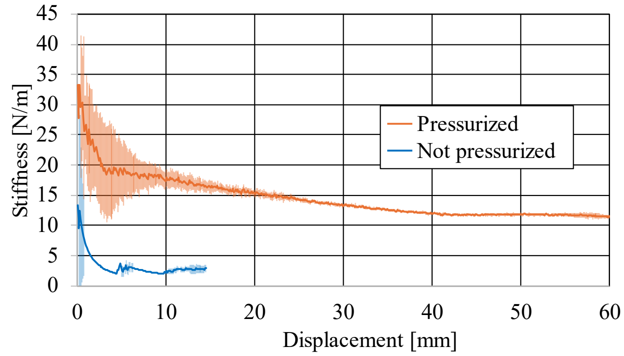


Figure 2. Experimental setup for evaluating the developd soft actuator for maintainng the shape of the sleeve cap

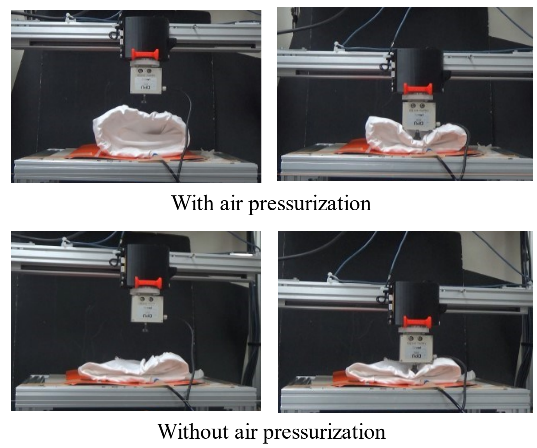
B. *Result*

Fig.3 shows the result of experiment. As shown in Fig. 3(a), when pressurized with air, the shape of the sleeve cap was maintained and the reduction in stiffness was suppressed to more than 10 N/m. On the other hand, when not pressurized, the shape of the sleeve cap was not maintained and the stiffness dropped to nearly 0 N/m.

Fig. 3(b) shows the deformation of the sleeve cap under applied load. When the soft actuator is pressurized with air, the shape of the unloaded parts of the sleeve cap is maintained even when load is applied. Conversely, if the soft actuator was not pressurized, applying load to the sleeve cap results in the deformation of the entire sleeve cap, causing it to collapse. when the actuator pressed by the load cell, only the pressed part is deformed. These results show that the developed soft actuator can increase the stiffness of the sleeve cap and maintain its shape.



(a) Stiffness vs. displacement of the sleeve equipped with the soft actuator



(b) Deformation of the sleeve cap under applied load

Figure 3. Stiffness vs. displacement of the sleeve equipped with the soft actuator for maintaining the shape of the sleeve cap, and the deformation of the sleeve cap with and without air pressurization

IV. Functional Evaluation

A. *Experimental procedure*

The participants were 8 students (6 males and 2 females with an average ag of 22.4 ±1.30). The participants were instructed to extend their arm parallel to the ground and to wear the developed sleeve from their wrist to their shoulder for 5 seconds each, both with and without air pressurization. After removing the sleeve, the participants respond on a Likert scale regarding space, discomfort, ease of dressing and undressing, ventilation, and changes in wearing comfort, comparing the conditions with and without air pressurization.

B. *Result and discussion*

Fig.4 shows the result of the experiment. Significant differences were observed in terms of space and ease of dressing and undressing. The results indicate that increasing stiffness and reducing friction improves the ease of dressing and undressing. Furthermore, it was found that, as shown in Fig. 5, it was found that the sleeve could be undressed without twisting or wrinkling if pressurizing with air to maintain its shape.

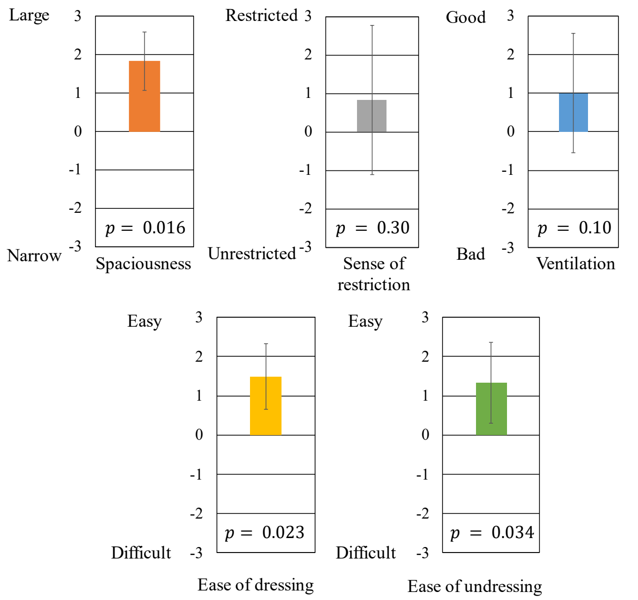


Figure 4. Participants' responses on space, sense of restriction, ventilation, and ease of dressing and undressing, comparing the conditions with and without air inflation; e.g. a positive score indicates large speciousness while a negative score indicetes narrow speciousness

Figure 5. Shape of the develoepd sleeve during undressing (Left :without air pressurization, Right: with air pressurization)

V. CONCLUSION

This study presented a novel soft actuator integrated into a garment to increase its stiffness for shape maintenance, while simultaneously reducing the friction between the skin and garment. The improved shape retention in the sleeve cap and along the sleeve's longitudinal direction, coupled with the friction reduction, facilitated easier dressing and undressing. The functionality was confirmed through the evaluation tests by human subjects. Future work will involve developing an upper-body garment incorporating the soft actuator and conducting further investigations in more practical situations.

VI. ACKNOWLEDGEMENT

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